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PILOT PLANT STUDY OF THE EFFECT OF A SURFACE ELECTRIC FIELD ON FABRIC FILTER OPERATION

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16. ABSTRACT The paper gives results of a pilot plant study of electrostatically augmented fabric filtration (ESFF) to transfer laboratory technology to the field environment. (Note: Electrostatic fields at the fabric surface of fabric dust collectors have been observed in the laboratory to reduce the flow resistance of the collected dust and to reduce the dust penetration into the fabric.) Conclusions include: (1) using an electric field parallel to the fabric surface, without particle charging, to enhance fabric filter operation is operable at pilot scale (the pilot plant operated on flue gas from an industrial boiler); (2) the electrical hardware developed for the pulse-cleaned baghouse is workable and durable in the operating environment and has potential for commercial use; (3) at any given face velocity, the ESFF baghouse has a reduced residual pressure drop and a reduced rate of pressure drop increase when compared with a conventional fabric filter; (4) the pulse-cleaned ESFF baghouse could be operated in a stable fashion at filter face velocities up to about twice that at which the conventional baghouse was stable; and (5) the pilot unit results are consistent with dust cake expansion and lowered porosity due to a tendency to form dendritic structures as the dust cake collects.

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Electrostatics	Viscosity	Stationary Sources	20C	20D
Filtration		Fabric Filters	07D	
Fabrics		ESFF	11E	
Dust		Particulate	11H	
Particles		Flow Resistance	14H	

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ABSTRACT

Electrostatic fields at the fabric surface of fabric dust collectors have been observed in the laboratory to reduce the flow resistance of the collected dust and to reduce the dust penetration into the fabric. A pilot plant study of electrostatically augmented fabric filtration was undertaken to transfer the laboratory technology to the field environment. Pilot plant results are presented. These results are interpreted with respect to dust cake structure and properties.

INTRODUCTION

Conventional Fabric Filtration

Filtration to separate particulate from gas streams dates back to Roman times.[1] Fabric filtration as a means of industrial air pollution control is much more recent, but is well established in a number of applications. The technology is being increasingly applied to coal-fired boiler emission control. The very high particulate removal efficiency of fabric filtration and competitive economics, coupled with the difficulties electrostatic precipitators have with high-resistivity fly ashes, have given filters a significant boost in popularity. The major drawback for fabric filters in coal-fired boiler applications has been unexpectedly high pressure drops at some installations. Reduction of the pressure drop of fabric filters is thus important and may significantly influence the choice of particulate control equipment.

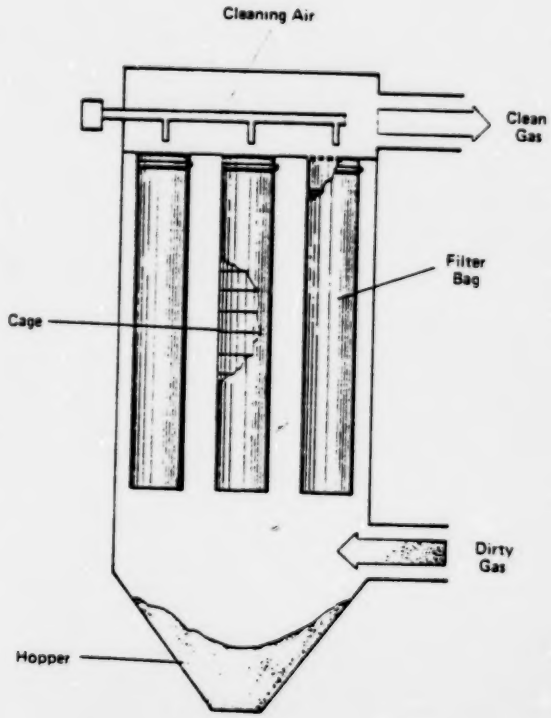

Figure 1. Simplified fabric filter.

Commercial fabric filters have the general features of the simplified filter shown in Figure 1. Large numbers of cylindrical fabric bags are suspended within a housing. Dirty gas enters the housing and is drawn through the fabric. The suspended dust collects on the fabric surface while the cleaned gas passes through the fabric and exits the baghouse. Periodically, the accumulated dust must be removed. Two common cleaning methods are pulse and reverse-air cleaning. In pulse cleaning, a roughly 50-ms pulse of approximately 655 kPa air is injected into the top of a bag, such as the one shown in Figure 1. Cleaning is primarily by bag distortion as the pulse-induced shock wave moves down the bag. The cleaning action is relatively intense. Normally relatively heavy fabrics are used to reduce dust penetration. Reverse-air cleaning is a gentler method and is used for lighter fiberglass bags which collect dust on the inside, and are most popular for utility baghouses. Cleaning is accomplished by fracturing the filter cake when the bag deflates due to the reverse-air flow.

The important parameters for baghouse operation are the pressure drop across the filter and the particulate collection efficiency. The particulate collection efficiency of a leak-free fabric filter is normally greater than that required by regulatory authorities, so usually successful operation is defined as the achievement of an acceptable pressure drop. The pressure drop is often expressed as the sum of the pressure drop due to the cleaned fabric and that due to the collected dust cake:

$$\Delta P = K_1 V + K_2 C_{ma} V \qquad (1)$$

where

ΔP = filter pressure drop, N/m^2

K_1 = constant, empirically determined, which expresses the flow resistance of the cleaned fabric, $N \cdot s/m^3$

V = face velocity through filter, m/s

K_2 = constant, empirically determined, which expresses the flow resistance per unit mass of dust cake, s^{-1}

C_{ma} = areal mass density of the dust on the bag, kg/m^2.

K_1 in Equation (1) must be determined after the filter has been in operation for some time and has achieved steady-state operation (the quantity of dust remaining on the fabric after cleaning has become constant).

Electrostatic Enhancement of Fabric Filtration

The electrical phenomena which occur in all fabric filters are not normally considered in the design of a filter. Research has shown, however, that the electrostatic potentials reached even in a conventional baghouse are considerable. The deliberate use of electrostatic effects to improve the performance of fabric filters has only recently received commercial consideration. The performance of the filter can be improved by charging the particles or by applying an electric field near the fabric surface.

Reduction of fabric filter pressure drop can be achieved in two general ways. First, if the electrostatic forces result in increased particle collection at the fabric surface (reduced filtration in depth), cleaning could be expected to be more efficient and the residual pressure drop (K_1V in Equation (1)) reduced. Second, if the electrically influenced particle-to-particle and particle-to-fabric interactions result in a dust cake that is more porous than normal, the flow resistance of the collected dust cake ($K_2C_{ma}V$ in Equation (1)) would be reduced.

The electrical forces between a fiber and a particle can be coulombic, dielectrophoretic, or image charge effects. The expressions for the particular case of the interaction of a single cylindrical fiber with a spherical particle in air are summarized in Table 1.[2] For dust and fabric parameters reasonable for conventional fabric filtration, coulombic forces are dominant. Dielectrophoretic forces are next in magnitude, and the image charge forces are much weaker.[3]

The deposition of particles on single fibers has been studied by a number of researchers, both experimentally and by mathematically modeling the system.[4 5 6] Experimentally, particles collected on a single fiber under the influence of an electric field have a greater tendency to form chain-like aggregates (dendrites) than without the electric field. The mathematical models of this situation have been at least qualitatively successful at predicting the behavior of the system. The formation of a

TABLE 1. ELECTRICAL FORCES IN THE FABRIC FILTER ENVIRONMENT

Type of interaction	Force
Coulombic	$\frac{2Qq_p}{r}$
Image-charge	$-\frac{k_1' - 1}{k_1' + 1}\frac{q_p^2}{4r^2}$ $(Q = 0)$
Dielectrophoretic	$-\frac{k_2' - 1}{k_2' + 2}\frac{d_p^2 Q^2}{2r^3}$ $(q_p = 0)$

NOTE: Q = fiber charge/unit length

q_p = particle charge

r = distance between particle center and the fiber surface

k_1' = dielectric constant of fiber

k_2' = dielectric constant of particle

d_p = particle diameter

dendritic particulate collection would have potential for reducing the dust cake flow resistance. In addition, particulate would tend to collect closer to the fabric surface, reducing the residual pressure drop. A photomicrograph of a fabric filter dust cake that displayed obvious dendritic character has not been reported in the literature; the experimental difficulties are formidable.

Electrostatic forces can be utilized in fabric filtration by allowing the natural particle charges to accumulate on the fabric, by charging the particles and then collecting the particles, and by applying an electric field at the fabric surface. The first category describes many existing fabric filters; it is the natural result of collecting charged dusts on nonconductive fabrics. A commercially available device, the Apitron™, utilizes the second approach. The incoming particles are charged, and a significant portion collected, within the precharger. The remaining dust is collected, and charge accumulation by the fabric and collected dust

causes an electric field to develop, which further enhances collection. The third method is that used in the work described in this paper, in which an electric field is applied at the fabric surface. The particles are not deliberately charged.

The electrostatic enhancement concept utilized in this work was developed at the Textile Research Institute (TRI).[7] The development work was done at ambient conditions in laboratory apparatus. The dust used was resuspended fly ash. The electric field was parallel to the fabric surface. The TRI work indicated that an electrostatically enhanced fabric filter could be operated with considerably reduced dust cake flow resistance at low power levels. Several fabrics were tested at a range of electrical conditions, and the results were, in general, encouraging. Dust cake flow resistance was reduced as much as 90 percent, the particulate collection efficiency was improved, and the electrical power consumption remained low. Several empirical guidelines for successful design of this form of electrostatic enhancement were developed. In summary, these are (1) that the field electrodes be located on the dust cake side of the fabric; (2) that the electrodes be on the fabric surface, but not incorporated into it; and (3) that a fabric of low upstream surface density improved performance.

Pilot Unit

The test data reported in this paper were collected from a pilot unit, using electrical hardware similar to that developed by TRI. The pilot unit was operated on a slipstream from an industrial pulverized coal boiler baghouse. The coal fed to the boilers was highly variable; thus the physical and electrical properties of the fly ash also varied in time.

The basis of the ESFF (electrically stimulated fabric filtration, a TRI-coined acronym) pilot-unit test program was parallel operation of identical conventional and ESFF compartments. That the two compartments be truly identical and have identical inlet conditions was critical to the test plan. Comparisons of the compartments' operation without ESFF, inlet dust loading and particle size checks, flow measurement, and hopper dust collection checks were all used to ensure consistent operation. Boiler and coal variations were too large for successful testing to be done consecutively in time.

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Figure 2 is a schematic diagram of the pilot-unit installation. The pilot-plant capacity was about 9 m^3/min (300 ft^3/min) in each compartment; average inlet mass loading was about 0.7 g/m^3 (0.3 gr/scf). The inlet temperature was around 150° C (300° F). The baghouses were first operated as on-line pulse-cleaned units. During this period, each baghouse was operated with up to five bags, 11.5 cm (4.5 in.) in diameter, and 2.44 m (8 ft) long. The baghouse was designed to be converted easily to reverse-air cleaned, and when configured for reverse air operation, up to nine bags, each 20.3 cm in diameter and 2.44 m in length, were used. The electrical hardware consisted of high-voltage DC power supplies, current and voltage instrumentation, and the ESFF electrodes. The voltage remained on the electrodes during cleaning. Operation was 24 hours each day while a test was in progress.

Several electrode designs were used over the course of the pilot unit test program. All utilized vertical electrodes of alternate polarity.

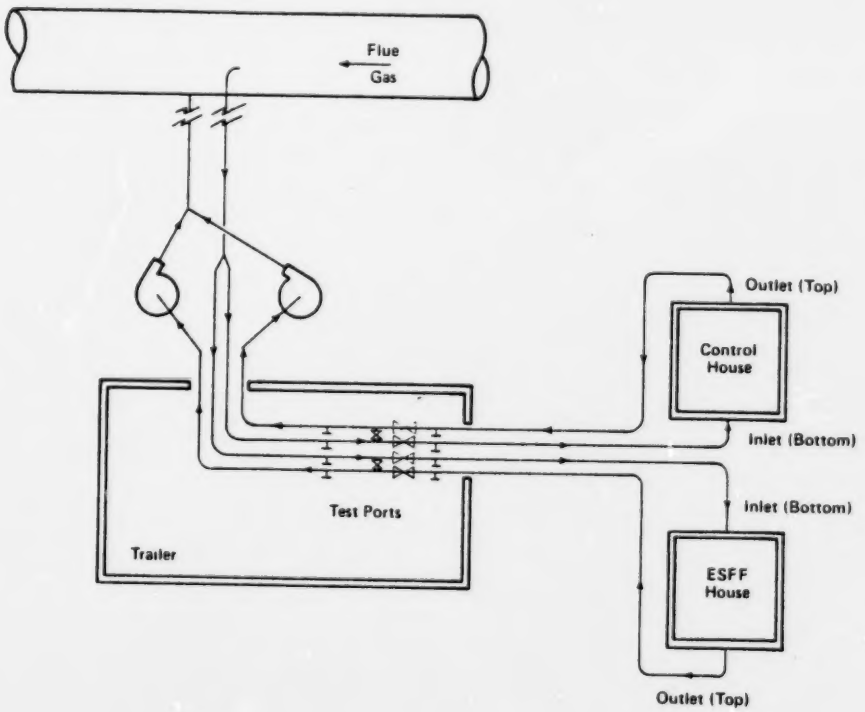

Figure 2. Schematic of ESFF pilot unit.

The most practical designs to date have been arrays of wires separated by insulating spacers, as shown in Figure 3. These have been mounted on the clean side of the fabric, in contrast to laboratory evidence that it was necessary to have the electrodes on the dust-cake side. The difference has not been explained, but clean-side electrodes gave performance equivalent to the others at the pilot unit, and they have significant advantages with respect to durability and ease of use. For a pulse-cleaned baghouse, the electrodes are located on the inside of the bag and double as the bag support cage. For a reverse-air baghouse, the electrodes are mounted on the outside of the bag, allowing the normal collapse of the bag during cleaning.

Pulse-cleaning results and preliminary reverse-air-cleaning results are presented in this paper. The reverse-air program is continuing at this time, and the test program is not complete.

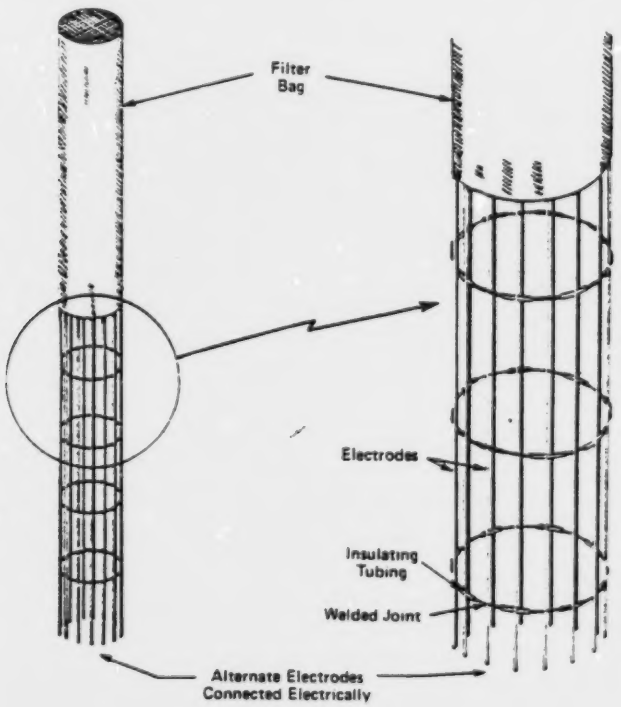

Figure 3. Example pilot unit ESFF electrodes.

EXPERIMENTAL RESULTS AND DISCUSSION

Dust Cake Flow Resistance

From the standpoint of operating a fabric filter, the most important result obtained at the ESFF pilot unit is the improvement in the pressure drop characteristics of the filter. The effect of electrostatic augmentation on dust cake flow resistance can be observed readily in a plot of pilot unit pressure drop as a function of time, as shown in Figure 4 (pulse-cleaned) and Figure 5 (reverse-air). The data shown in Figure 4 are for four cycles of pulse-cleaned operation with cleaning every 15 minutes. The pressure drop of the ESFF baghouse does not increase as rapidly. As the same amount of dust is being deposited on the bags in both baghouses, at the same flow rate, the difference must be in the flow resistance of the dust cake.

This reduction in dust cake flow resistance has been quantified as a pressure drop ratio (PDR), defined as:

$$PDR = \frac{(\Delta P_f - \Delta P_i)_{ESFF}}{(\Delta P_f - \Delta P_i)_{conv}} \qquad (2)$$

where

ΔP_f = pressure drop just prior to cleaning

ΔP_i = pressure drop just after cleaning

ESFF = the ESFF compartment

conv = the conventional compartment.

For an idealized dust collection cycle in which the pressure drop versus time plot is linear, PDR is the ratio of the specific dust cake resistances (K_2 in Equation 1). Figure 6 presents the relationship between PDR and electric-field strength for fiberglass and Teflon® fabrics for a range of face velocities. Figure 6 shows that at 3×10^5 V/m the increase in pressure drop for the ESFF compartment over a cleaning cycle was a little less than half that for the conventional compartment. PDR was not a strong function of field strength beyond 1×10^5 V/m for either woven fiberglass or felted Teflon® fabrics. The reverse-air data shown are preliminary data from the

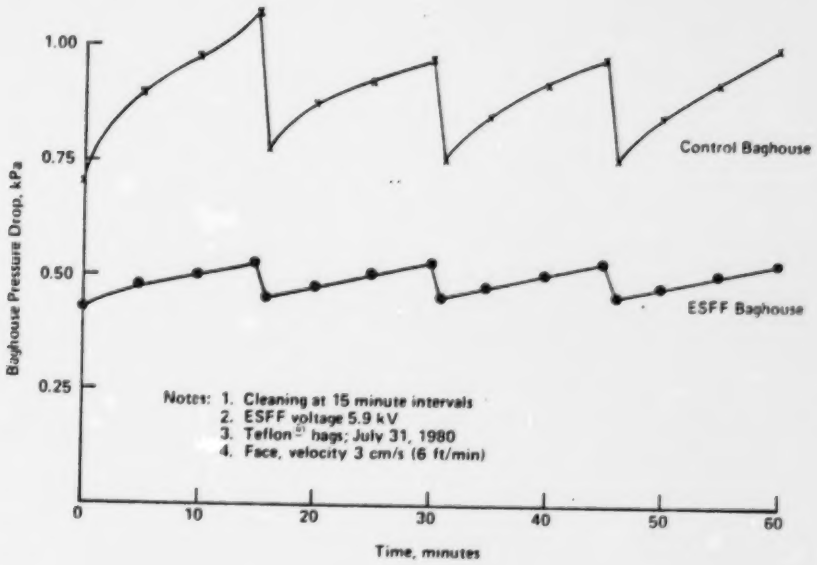

Figure 4. Pressure drop over several cleaning cycles for pulse-cleaned operation.

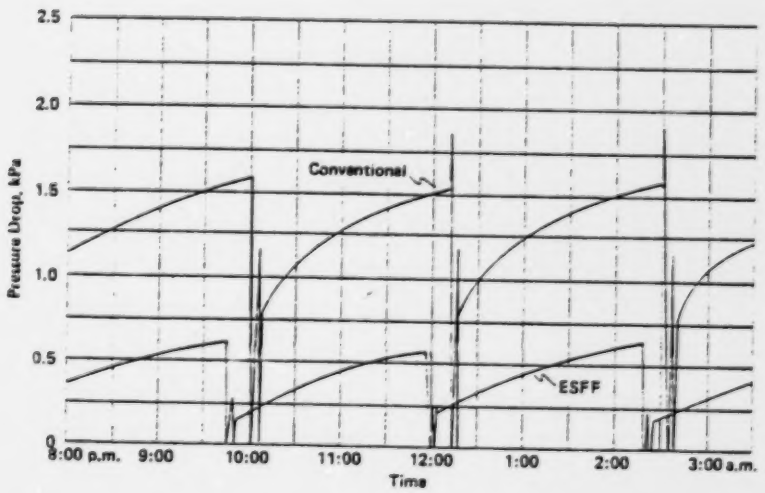

Figure 5. Pressure drop over several cleaning cycles for reverse-air-cleaned operation.

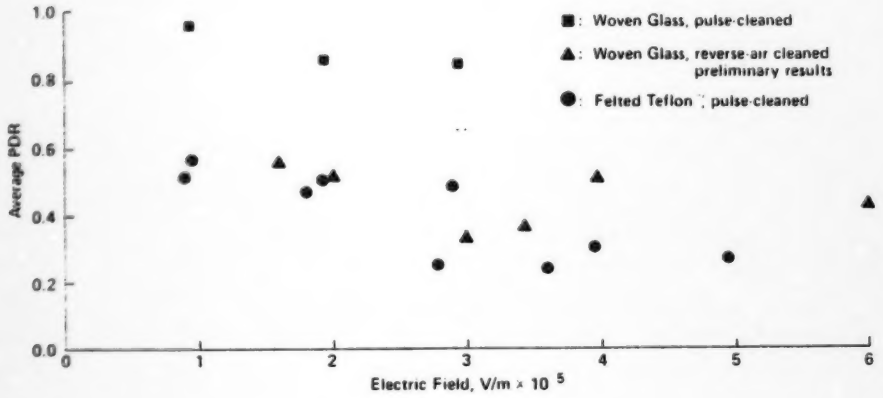

Figure 6. PDR as a function of field strength.

continuing test program. The laboratory results obtained by TRI for Teflon® fabrics are in general agreement with the pilot unit data.

These results (reduced dust cake flow resistance) are consistent with the formation of dendritic structures due to the influence of the electric field, as has been observed in the single-fiber studies. No structures were readily visible in the pilot unit dust cake, nor were there any patterns that indicate thicker dust cakes over either electrode polarity, although such visual differences have been observed in the laboratory.[7] It is of interest that bulk density measurements of the dust collected in the hoppers of the baghouses indicated that the average bulk density of the ESFF fly ash, at 0.23 g/cm^3, was 85 percent of the average bulk density of the fly ash collected in the conventional baghouse.

The Kozeny-Carmen equation describes very slow flow through a packed bed:[8]

$$\Delta P = \frac{150\ V_o L\ \mu\ (1-\varepsilon)^2}{d_p^2\ \varepsilon^3} \qquad (3)$$

where

ΔP = Pressure drop across bed of solids, N/m^2

V_o = Face velocity, m/s,

L = Thickness of bed, m

μ = Fluid viscosity, kg/m·s

ε = Void fraction, volume of voids/volume of bed, dimensionless

d_p = Particle diameter, m.

For the experimental conditions of the pilot unit, the velocity, viscosity, and particle diameters are the same, and a ratio of the pressure drops of the two baghouses may be set up:

$$\frac{\Delta P_{ESFF}}{\Delta P_{conv}} = \frac{L_{ESFF}\,(1-\varepsilon_{ESFF})^2\,\varepsilon^3_{conv}}{L_{conv}\,(1-\varepsilon_{conv})^2\,\varepsilon^3_{ESFF}} \tag{4}$$

For a case where the ESFF pressure drop increase over a cycle is half that of the conventional baghouse, and the thickness of the conventional baghouse dust cake is 85 percent that of the ESFF dust cake (as indicated by the bulk density measurements), Equation (4) becomes:

$$0.40 = \frac{(1-\varepsilon_{ESFF})^2\,\varepsilon^3_{conv}}{(1-\varepsilon_{conv})^2\,\varepsilon^3_{ESFF}} \tag{5}$$

To examine the probable change in the cake porosity due to the ESFF effect, the conventional porosity will be estimated[9] as 0.5. For this estimate of porosity, the calculated porosity of the ESFF dust cake is 0.59, an increase of 18 percent. The analysis presented above indicates the magnitude of the porosity changes which the ESFF effect introduces into the dust cake.

Cleaned Fabric Flow Resistance

Another advantage of ESFF is evident in Figures 4 and 5. The cleaned fabric pressure drop (ΔP_r) is less for the ESFF baghouse than for the conventional baghouse, corresponding to a reduced K_1 (from Equation 1). During the history of a fabric filter, the ΔP_r starts at a very low value when the virgin fabric is placed in the baghouse, and increases fairly rapidly to a steady-state ΔP_r. The data in Figure 4 are from bags which have been operated for about 3 months. The dust has penetrated into the interstitial pores of the fabric filter, increasing the pressure drop as

well as the particulate collection efficiency. The flow resistance of this dust-fabric structure is not amenable to calculation. The ESFF field reduces the penetration into the fabric, yielding a reduced pressure drop. Laboratory data indicated the reduced penetration,[7] but did not conclusively show the reduced ΔP_r.

Reverse-air pilot unit data were similar (Figure 5), but the amount of improvement is not as great.

Dust Cake Development

It is evident in Figures 4 and 5 that the conventional compartment operating pressure lines display much more curvature early in the filtering cycle than do the ESFF lines. The dust cake is forming and consolidating during this portion of the operating cycle, and true cake filtration occurs in the more linear portion of the curve. The difference in the cake formation portion of the curve was characteristic of the pulse-cleaned filter data, and was present in a large fraction of the reverse-air-cleaned operation. This phenomenon is important because a large fraction of the total pressure rise occurs during this portion of the cycle in the conventional compartment.

For the pulse-cleaned unit, the on-line cleaning removes to the hopper only a small fraction (in the range of 1 to 10 percent)[10] of the total dust on the bag. The electrical field apparently stabilizes the dust deposit without interfering greatly with cleaning efficiency. Similar considerations apply to the reverse-air-cleaned data, although the magnitude of the difference is less and was not present in all data.

Electrical Characteristics

The range of electric fields applied was up to 6×10^5 V/m with the majority of the data taken in the range of 2×10^5 to 4×10^5 V/m. This is a nominal field strength obtained by dividing electrode voltage difference by electrode spacing. Currents generally were about 15 to 30 $\mu A/m^2$ of bag surface. For normal pulse-cleaned operation, the current did not rise steadily with time as dust accumulated on the bag. The reverse-air-cleaned ESFF current has been of about the same magnitude and has had similar characteristics. Increases of current that apparently track the dust

accumulation on the fabric have been observed in the reverse-air mode, although not regularly. For both pulse- and reverse-air-cleaned operation, boiler operation that would be expected to yield high carbon ash has caused high currents. Due to power supply limitations, the voltage drops sharply as the current rises to around 400 $\mu A/m^2$. Normal cleaning of the bags has restored operation in most instances.

Operating Filtration Velocity

For a given amount of cleaning and inlet dust loading, there is a filtration velocity limit[10] above which a particular filter will not operate in the stable manner shown in Figures 4 and 5. The dust accumulates too rapidly, and the cleaning is less effective at the high gas rates. It has been found at the pilot unit that an ESFF fabric filter (particularly pulse-cleaned) can be operated at an increased face velocity. Figure 7 demonstrates this situation.

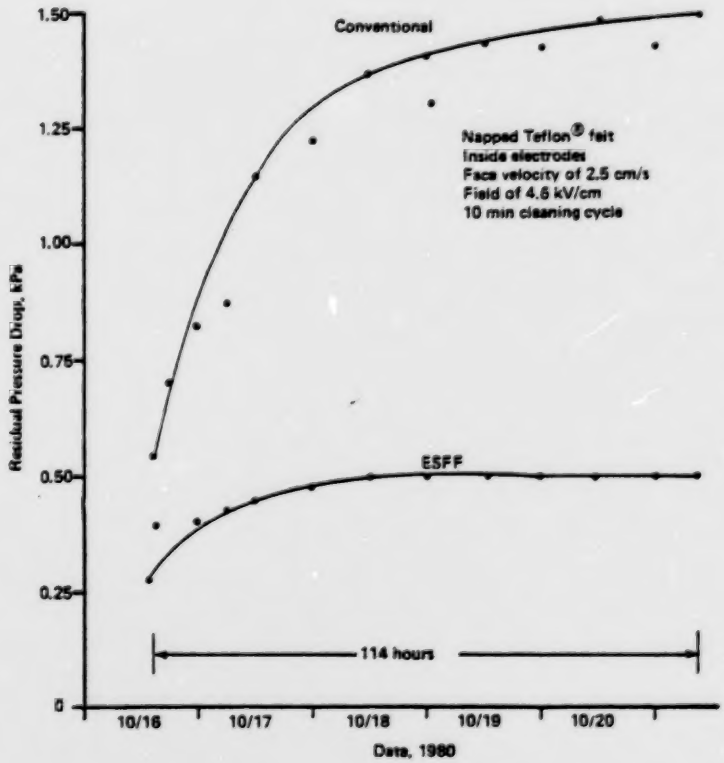

Figure 7. Increased face velocity operation for ESFF baghouse.

This ESFF advantage is simply another aspect of the operating mechanisms discussed earlier. It is particularly important from a practical standpoint, as a baghouse which can be operated at twice the face velocity of the conventional baghouse can be half the size of the conventional unit, and with correspondingly attractive economics. For the pulse-cleaned unit, economic estimates have indicated a 30-percent annualized cost advantage if the ESFF baghouse is operated at 1.5 times the face velocity of a conventional baghouse.

Again, the reverse-air results have been similar, but have not shown as great an advantage for the ESFF baghouse.

CONCLUSIONS

The concept of using an electric field parallel to the fabric surface, without particle charging, to enhance fabric filter operation has been shown to be operable at pilot scale. The pilot plant operated on flue gas from an industrial boiler.

The electrical hardware developed for the pulse-cleaned baghouse is workable and durable in the operating environment and has potential for commercial use.

At any given face velocity, the ESFF baghouse has a reduced residual pressure drop and a reduced rate of pressure drop increase when compared to a conventional fabric filter.

The pulse-cleaned ESFF baghouse could be operated in a stable fashion at filter face velocities up to about twice the velocity at which the conventional baghouse was stable. This capability makes the ESFF baghouse economically attractive for coal-fired boiler particulate control.

The pilot unit results are consistent with dust cake expansion and lowered porosity due to a tendency to form dendritic structures as the dust cake collects.

ACKNOWLEDGMENT

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